Utility Needs for Advanced Intelligent Inverters

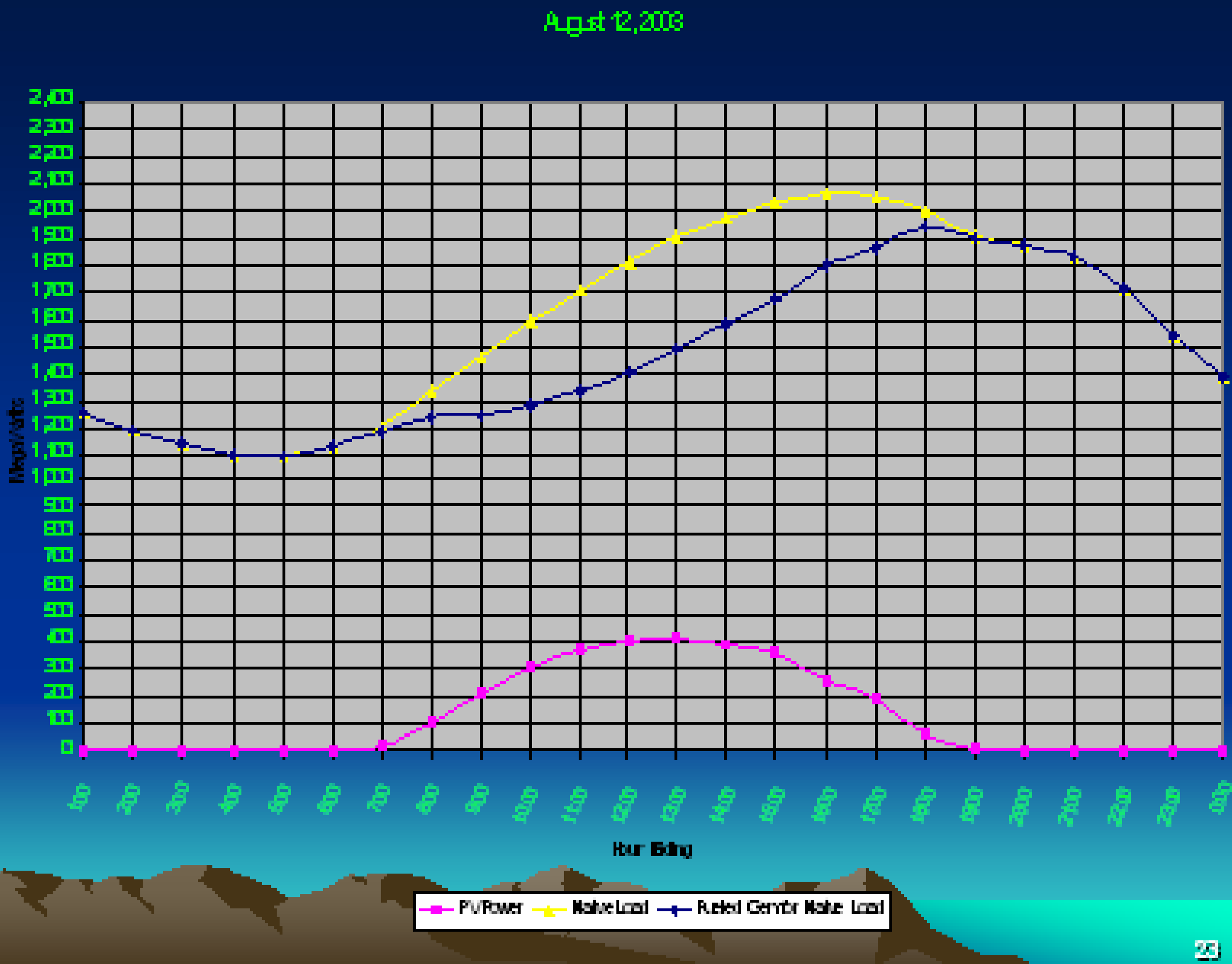
The TEP Solar EPS projects must integrate seamlessly with the WSCC grid or provide seamlessly for services

- Load following
- Spinning reserve
- Voltage Support – Power Factor
- Voltage and Frequency Control
- Frequency Droop Characteristic
- Generation Displacement Angle & Inertia Constant

Load Following

- Minimize inadvertent error to reduce ancillary service penalties
  - Without clouds, solar is highly predictable.
  - Clouds make solar unpredictable.
- Match generation to demand at peak times
  - Assume a 600 MW DC array system:
  - If south facing at latitude tilt, generation at peak hour of 18:00 on 08/12/2003 is 120 MW, with annual energy production of 1,050 GWh.
  - If west facing, at 35 degree tilt, generation at peak hour of 18:00 on 08/12/2003 is 115 MW, annual energy production of 780 GWh.
  - Clouds at 15:55 on 08/12/2003 reduced PV output to 100 kW for 5 minutes over the entire city simultaneously.
  - Medium term – four hour at full load - energy storage in the inverter could provide this service and revenue during non solar times for the utility if centrally dispatchable.
- Tradeoff between energy value and capacity value. No certainty on solar capacity if clouds are anticipated.
- Islanding – If the grid goes down, the inverter will stop producing power if the PV and inverter system has no energy storage.

Load Characteristics



Spinning Reserve

- WSCC requires spinning reserve of 7% of current load
  - For TEP this can be as much as 167 MW at peak hour in 2006.
  - TEP pays for spinning reserve - there is a cost for incremental need of this service. It could require running a gas turbine unloaded, increasing fuel use and peak hour emissions in the city of Tucson.
  - Short term – 15 minutes at full load - energy storage in the inverter could provide this service and revenue during non solar times for the utility if centrally dispatchable.
  - More data and study required to determine the effect of geographic diversity.

Voltage Support – Power Factor

- Power Factor Control for Voltage Support
  - Presently PV inverters operate at unity power factor, no vars lag or lead.
  - PV inverters in current output mode contribute nothing to grid voltage stability.
  - As PV inverter penetration increases, dispatchable vars will be supported by a smaller percent of total generation.
  - Ability for full range of var control will be diminished, leaving a greater opportunity for voltage collapse similar to problems seen prior to August 14^{th} northeast US grid failure.
  - Inverters need to be dispatchable for four quadrant operation, not one dimension operation as per present design.
  - Would require some small level of very short term – one second at full load - energy storage in inverter and appropriate redesign of power conversion software.
  - Could be a valuable service applied at the distribution feeder level.
  - Needs to be dispatchable at a central location with password protection.

Voltage & Frequency Control

- Voltage Trip Set Points
- Frequency Trip Set Points
- Frequency Droop Characteristic
- Generation Displacement Angle & Inertia Constant

Voltage Trip Set Points

- Voltage Trips per IEEE-929
  - PV inverter trip range presently set for +/- 12.5% in two cycles.
  - Utility recloser will actuate long after inverters have tripped.
  - Typical blinks from animal to line contact, lightning, etc will trip inverter but leave load operating, resulting in a loss of generation event.
  - As PV inverter penetration increases, this will further destabilize the generation/load balance during transients.
  - Have experienced events at SGSSS where inverters have tripped, but distribution line protection did not trip.
  - Maximum range of voltage trips should be extended to be +20%, -50% and provide a separate variable time delay up to one second for each trip variable.
  - Let individual utilities determine the appropriate set points within that range.
  - Allow for dynamic central dispatch of trip set points with password protection.
  - This is a need for the future “Smart Grid” technology implementation.

Frequency Trip Set Points

- Frequency Trips per IEEE-929
  - PV inverter trip range presently set for < 59.5 Hz and > 60.5 Hz in two cycles.
  - To prevent cascading blackouts, current utility load shed schemes actuate at 59.5 Hz, blacking out selected customer loads.
  - If generating PV inverters trip at 59.5 HZ the amount of required load reduction will be increased, causing cascade of the event to a greater degree than without PV inverters.
  - As PV inverter penetration increases, this will destabilize the generation/load balance during transients.
  - Numerous events at SGSSS occurred where inverters have tripped on low frequency, but distribution line protection did not trip.
  - Maximum range of frequency trips should be extended to be 57 Hz to 63 Hz and provide a separate variable time delay up to ten seconds for each trip variable.
  - Let individual utilities determine the appropriate set points within that range.
  - Allow for dynamic central dispatch of trip set points with password protection.
  - This is a need for the future “Smart Grid” technology implementation.

Frequency Droop Characteristic

- All fueled generators are designed with Droop
- Droop acts to increase generation during low frequency events to add capacity to the grid to raise frequency and bring load/generation back in balance
- Droop acts to decrease generation during high frequency events to reduce capacity on the grid to lower frequency and bring load/generation back in balance
- PV inverters are inherently in balance between DC input and AC output and have no ability, without energy storage, to increase load during a low frequency event, although by raising DC voltage they could reduce load during a high frequency event.
- PV inverters could be designed with Droop with software designed to produce a load reaction to frequency deviations and addition of some very short term – ten minutes at full load – energy storage

Generation Displacement Angle & Inertia Constant

- The frequency on the WSCC has become increasingly more volatile over the last 25 years
- Inertia constant acts to increase generation displacement angle during low frequency events, increasing instantaneous generation
- Inertia constant acts to decrease generation displacement angle during high frequency events, decreasing instantaneous generation
- The grid must have inertia to resist frequency transients during load or generation transients
- Hydro generators have very high inertia constant which anchors the grid frequency
- New generators like combustion turbines have significantly lower inertia constant and react to impulse frequency changes with less or no generation change
- PV inverters have zero inertia constant and will not change output due to a small frequency excursion
- PV inverters could be designed to act as if they had a high inertia constant with software developing a reaction to frequency deviations and addition of some very short term – one minute at full load – energy storage

Grid System Conclusions

- Inverter software will need to be revised to support Droop, inertia constant and four quadrant operation for voltage support control if PV is to provide its own ancillary services for grid interconnection.
- Short term – 15 minute - energy storage integral to the inverter for spinning reserve, frequency control - Droop, inertia constant and var control/support will become an increasingly important aspect of the future PV inverter grid interconnection.
- Medium term – four to six hour - energy storage is needed to maximize load following and energy production to optimize the generation capacity value of solar PV.
- PV inverter voltage and frequency protective functions provided to meet IEEE-929 need to be revisited to prevent future grid instability with increasing percentages of PV inverter generation. Wind machines are incorporating these changes now. This should include low voltage ride through capability per FERC standards for wind machines.
- **Until these characteristics are built into PV systems, fueled generation will have to provide these grid support services which reduces the value of PV generation - not a major utility concern at low PV penetration levels, but current PV inverters are not yet ready for energy security service.**

Other Future Considerations

- Development of Predictive maintenance algorithms to provide warning prior to failure of major inverter components.

- Development of high voltage (1000 vdc) inverters for more cost effective utility scale PV systems.